Exploring the Use of Mine Tailings in Cementitious Materials

A practical, quantitative pathway for circular, lower-carbon cement and concrete in Saudi Arabia and beyond

9th June 2026

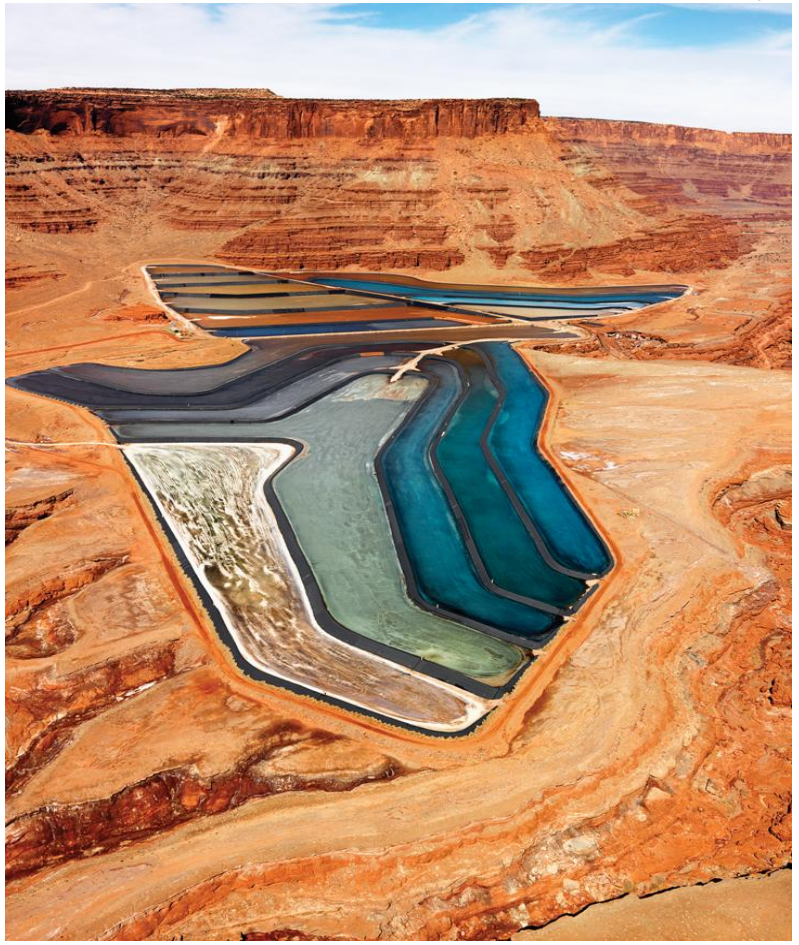
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RESILIENT INFRASTRUCTURE AND SUSTAINABLE MATERIALS LAB

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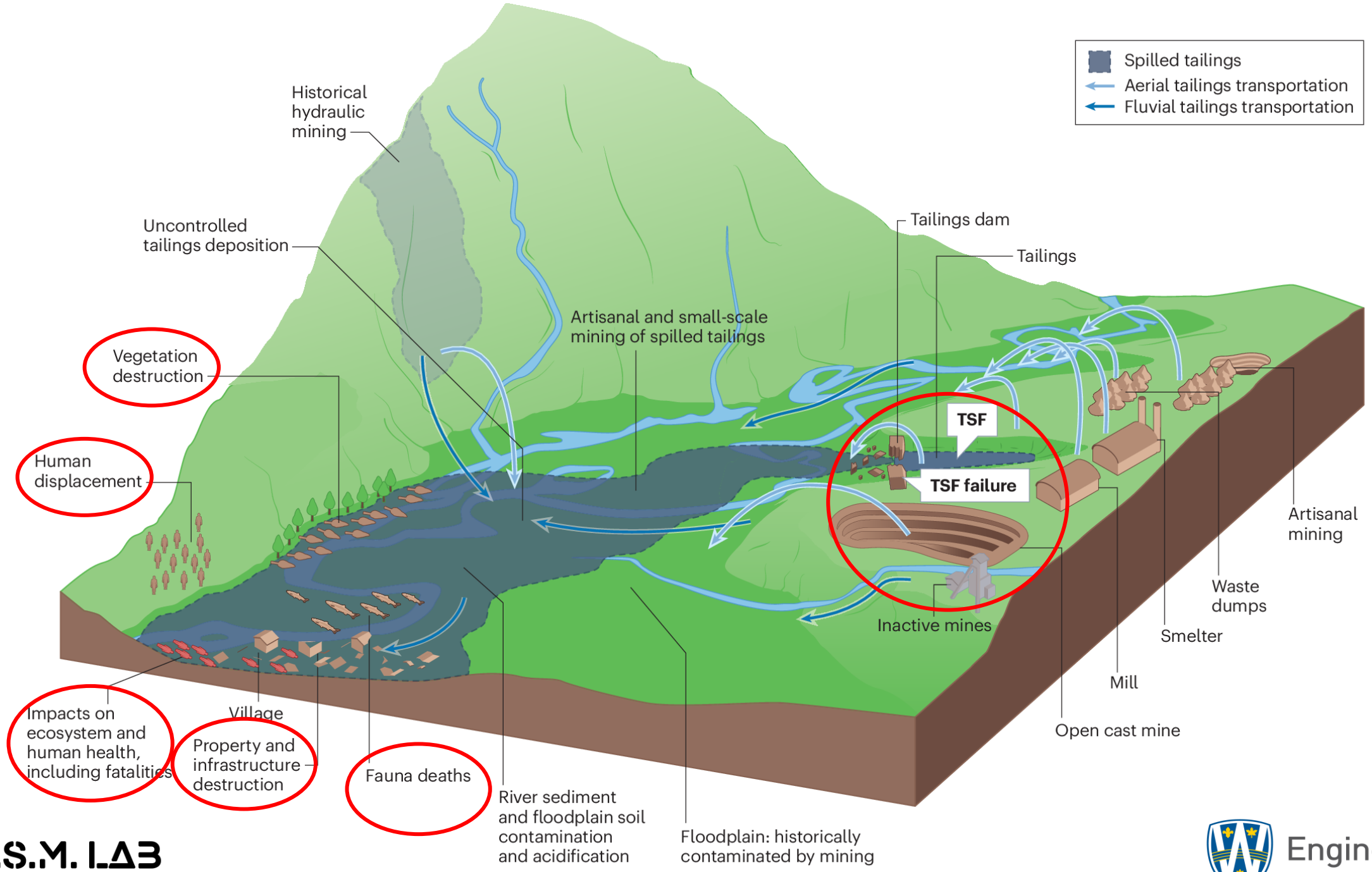
- Mining operations generate large volumes of mine tailings, posing environmental and management challenges.

- Improper disposal of MT can lead to soil, water, and air contamination.








Spilled tailings
Aerial tailings transportation
Fluvial tailings transportation
Historical hydraulic mining
Uncontrolled tailings deposition
Tailings dam
Tailings
Artisanal and small-scale mining of spilled tailings
Vegetation destruction
Human displacement
TSF
TSF failure
Artisanal mining
Waste dumps
Smelter
Mill
Open cast mine
Inactive mines
Impacts on ecosystem and human health, including fatalities
Village
Property and infrastructure destruction
Fauna deaths
River sediment and floodplain soil contamination and acidification
Floodplain: historically contaminated by mining



Retrogressive, rotational liquesfaction failures of tailings at Andavilque in Bolivia. Still from a video posted to Youtube.

The Landslide Blog is written by Dave Petley, who is widely recognized as a world leader in the study and management of landslides.

The impact of the 16 March 2025 tailings landslide at Andavilque, Bolivia continues to become apparent as the recovery operation is in full swing. News reports suggest that there were two fatalities and that 47 houses were destroyed. The government has committed to a full investigation, but we know that such promises are often not delivered.



Multiple Dams Fail at Indonesian Nickel-Mining Facilities

Ellen Moore | March 28, 2025 | SHARE:

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00:00 05:09

Three people are feared dead and hundreds more are at risk of negative health impacts after multiple tailings dams, which store toxic mine waste, collapsed inside an industrial park in Indonesia.

According to media and worker testimony, on March 16, the PT Huayue Nickel Cobalt tailings storage facility was breached, and liquified tailings flowed into the Bahadopi River. The breach flooded facilities at the Indonesia Morowali Industrial Park (IMIP) and the village of Labota with a wave of red water, putting the health of workers and 341 families at risk through exposure to heavy metals.



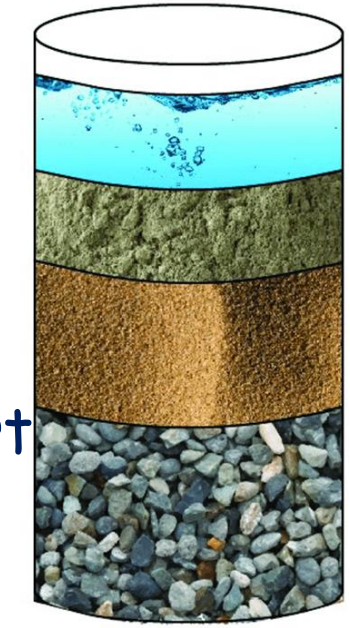
Zoe Sullivan
19 Dec 2017 Brazil

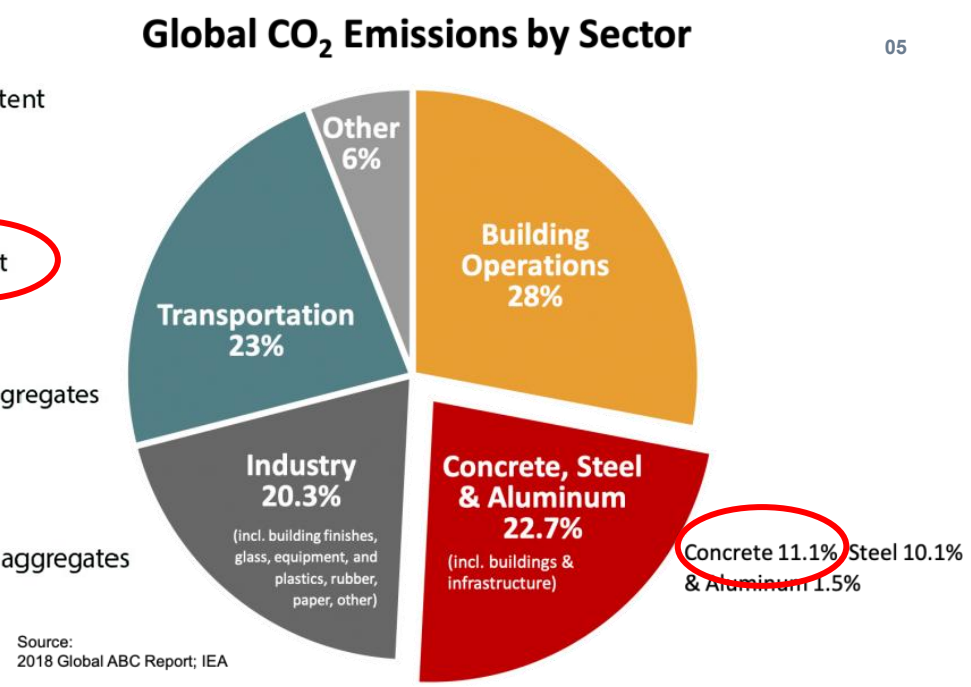
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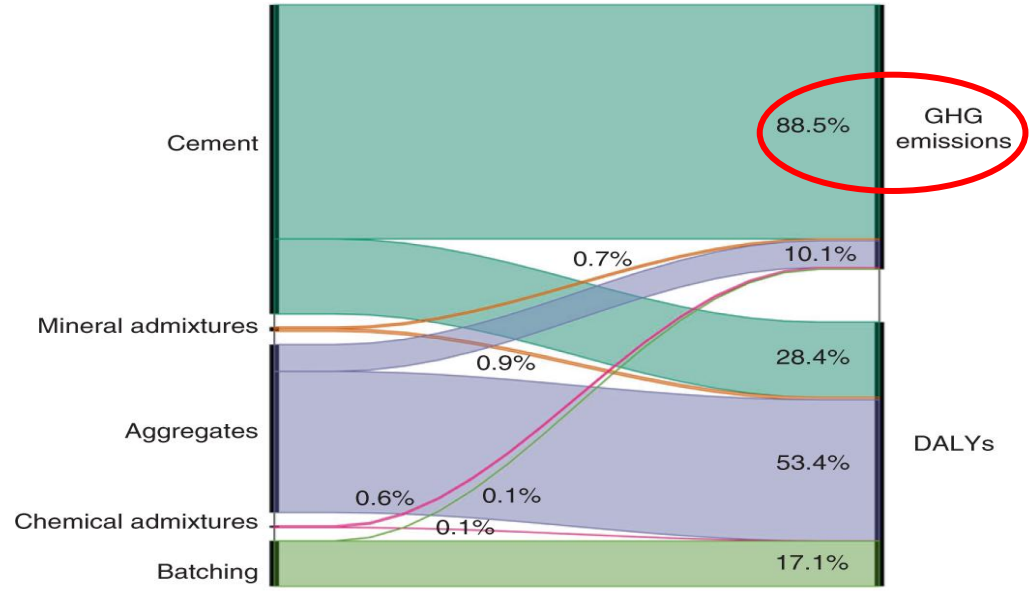


- *Between 2008-2017 it's estimated that more than 340 people died, communities have been ravaged, property ruined, rivers contaminated, fisheries wrecked and drinking water polluted by mining tailings dam collapses. Estimates from the year 2000 put the total number of tailings dams globally at 3,500, though there are likely more that have not been counted.*
- *A new United Nations Environmental Programme (UNEP) report states that as mining production escalates globally to provide the minerals and metals required for a variety of industrial needs, including green technologies, it is urgent that nations and companies address tailings dam safety.*

- Production of cement is responsible for over 3% of global emissions
- Transform MT from waste into value-added materials that support sustainable construction.
- Utilize mine tailings as a replacement for Portland cement (PC) in cementitious composites.
- Develop low-carbon, circular-economy materials while maintaining mechanical and durability performance.



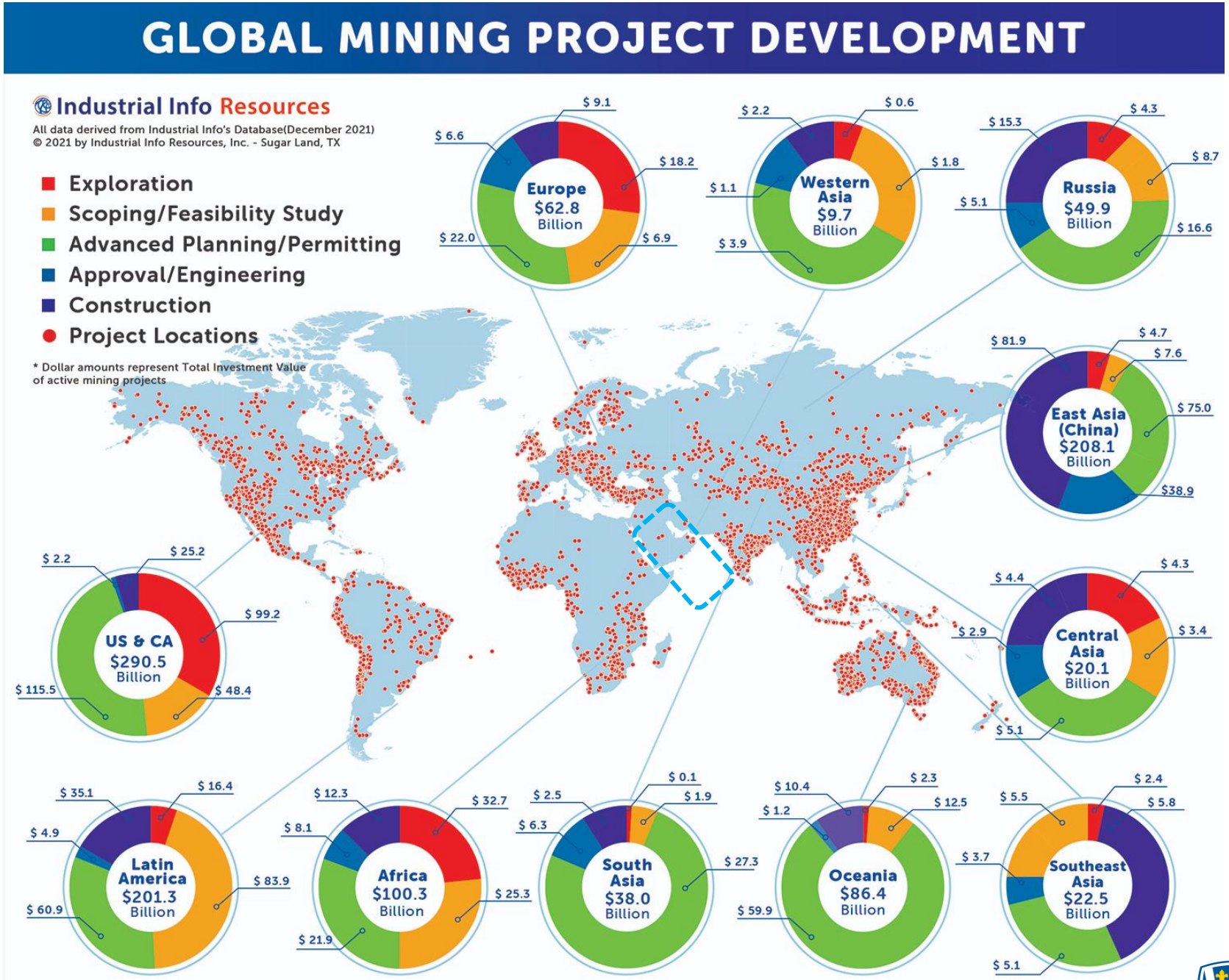




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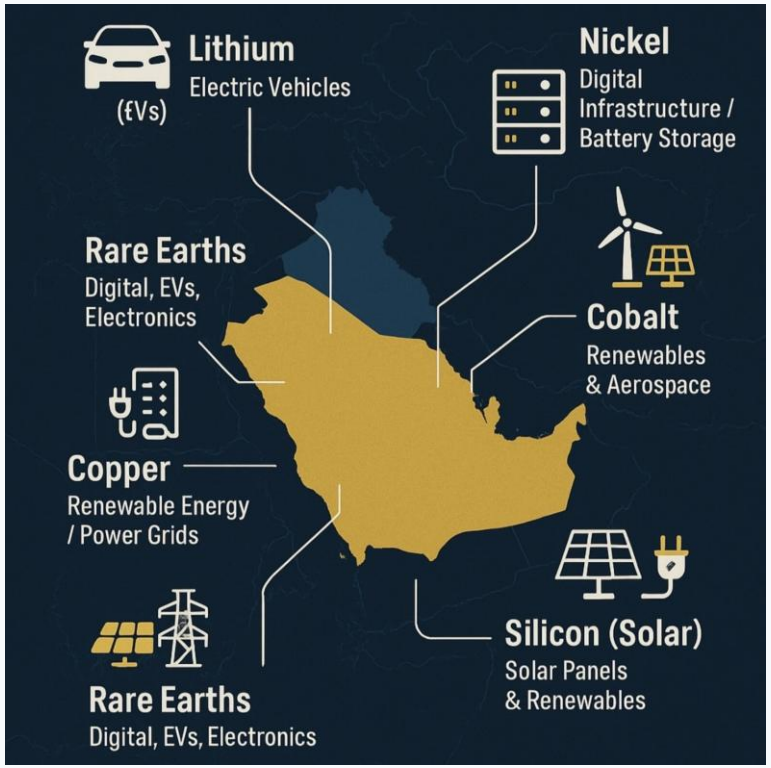
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GLOBAL MINING PROJECT DEVELOPMENT



Saudi's mining growth

- The Kingdom has upgraded estimates of untapped mineral resources to about $2.5 trillion.
- Exploration activity is expanding across gold, copper, zinc, lead, phosphate, bauxite and industrial minerals.
- Ma'aden operates across phosphate, aluminum, gold and base metals; Jabal Sayid is a key copper operation.



Modified from Al Majalla 2025

Tailings-to-cement opportunity areas

Copper / base metals
silicate-rich fines; sulfide and leaching checks are critical

Gold
fine quartz/aluminosilicate tailings; cyanide/reagent history must be assessed

Phosphate / bauxite
industrial-mineral residues; chemistry and sulfate/alkali controls required

Industrial minerals
silica, gypsum, clays, limestone streams may pair with cement production

The Saudi Arabia advantage

Cement demand, decarbonization pressure and mining growth are moving at the same time.

~80 Mt/y

Saudi cement demand projected by KAUST/FCI around 2030, driven by housing, industry and giga-projects.

KAUST FCI, 2025

278 $MtCO_2e/y$

Saudi Green Initiative 2030 emissions-reduction pledge. Cement and mining both sit inside the industrial transition.

SGI official

$2.5T

Estimated value of Saudi mineral resources; mining is positioned as the third pillar of the Saudi economy.

Reuters, PIF/Ma'aden

If cement demand grows while mining expands, a circular mineral-byproduct supply chain can be designed before legacy disposal patterns are locked in.

For cement producers

Secure local SCM/filler resources, reduce clinker exposure, build EPD-ready product lines and lower dependency on imported SCMs.

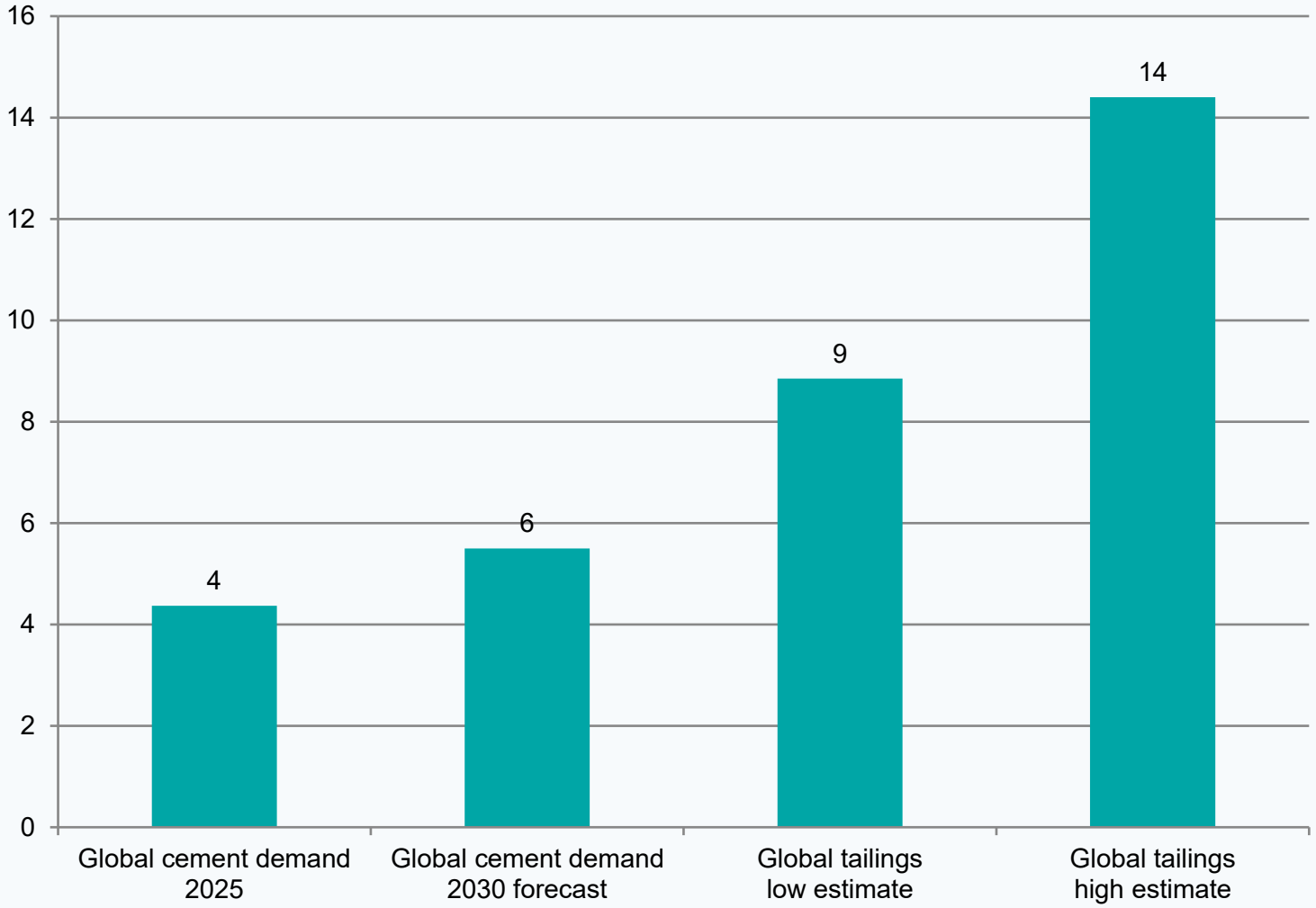
For mining companies

Turn tailings from a long-term liability into qualified construction feedstocks while strengthening ESG and tailings management narratives.

For regulators and giga-project clients

Create credible demand signals and performance-based pathways that reward verified low-carbon materials.

The scale is large enough to matter



Implication 1

Only a small fraction of tailings needs to be qualified to create multi-million-tonne cementitious material flows.

Implication 2

The limiting constraint is not global tonnage; it is source quality, variability, processing cost, logistics and acceptance.

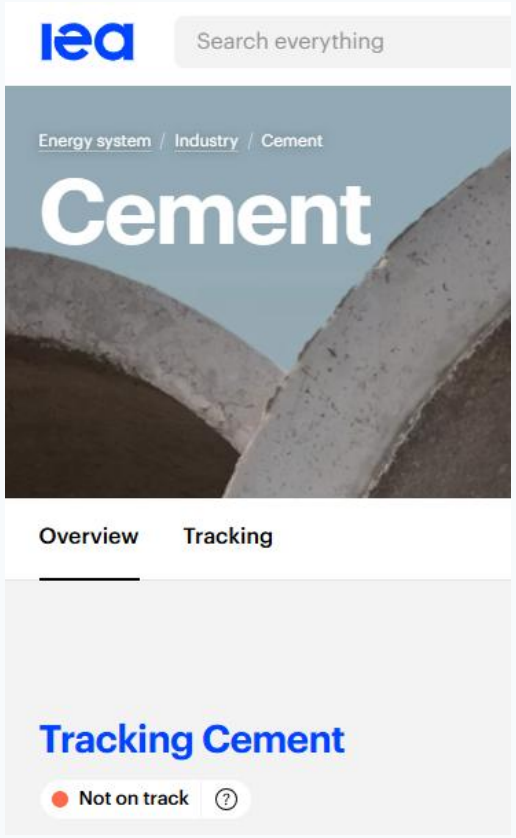
Implication 3

Tailings should be routed to the highest-value safe use, not forced into one universal cement replacement pathway.

Where tailings fit in cement decarbonization

Tailings are not a substitute for all levers, but they can strengthen the clinker-substitution and circularity pathway.

IEA: cement is not on track



Direct cement emissions intensity remains just under 0.6 tCO_2 per tonne of cement. Net-zero pathways require faster reductions through clinker substitution, efficiency, fuels, material efficiency and CCS.

Clinker substitution
SCMs, limestone, calcined clays, natural pozzolans, qualified tailings

Material efficiency
lower binder content, optimized packing, performance-based concrete

Low-carbon energy
waste heat recovery, alternative fuels, renewable electricity

CCS / near-zero
residual process CO_2 capture and storage where feasible

Demand creation
EPDs, green procurement, standards and certification

Tailings contribute when they displace clinker/binder, reduce virgin aggregate demand, or enable mine-site infrastructure with lower binder intensity.

Create a material passport before a mix design

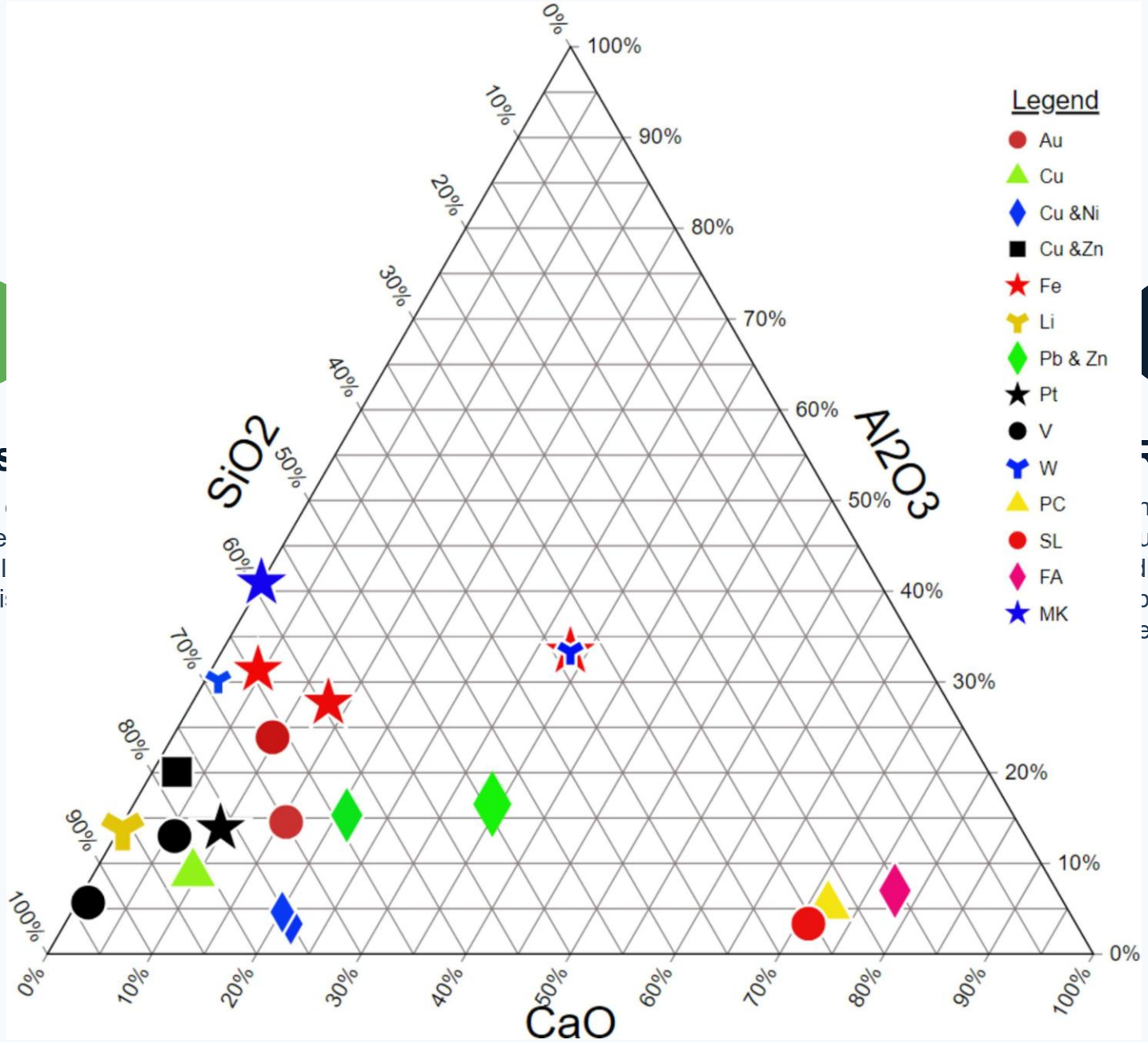
1 → 2

Identity

Mine, ore body, process route, age, sampling location, planned production tonnes.

Chemis

XRF major
trace me
sulfates/chl
LOI; alkali



6

Risk

ng, acid-base
unting, dust,
lioactivity,
bility and QA
equency.

Chemistry/mineralogy decision matrix

Signal	Filler / aggregate candidate	SCM candidate	AAM / hybrid candidate	Reject or contain until controlled
Si–Al glass or reactive aluminosilicate	not required	highly desirable	very desirable	low if absent
Fine PSD / high surface	helps packing, raises water demand	can increase reaction and water demand	helps dissolution	problem if dust risk high
Sulfides / acid generation	screen carefully	major durability risk	stabilization possible but test	exclude if not controlled
Metals / soluble salts	leaching gate	leaching + setting impacts	immobilization must be proven	exclude if release exceeds limits
High quartz / crystalline inert phases	good filler/sand if graded	low reactivity without activation	needs activation/blending	not a binder by itself

Chemistry identifies potential; mineralogy and reactivity decide whether that potential is real; durability and leaching decide whether it is deployable.

Utilization lanes for high-volume deployment

Each lane has a different risk, volume, processing and value profile.



Lane 1 — Mine backfill & mine infrastructure

Very high volume; controlled environment; quickest route for high tonnage.

Lane 2 — Fine aggregate / filler

Blocks, pavers, mine roads, RCC, non-structural concrete; moderate processing.

Lane 3 — SCM / cement replacement

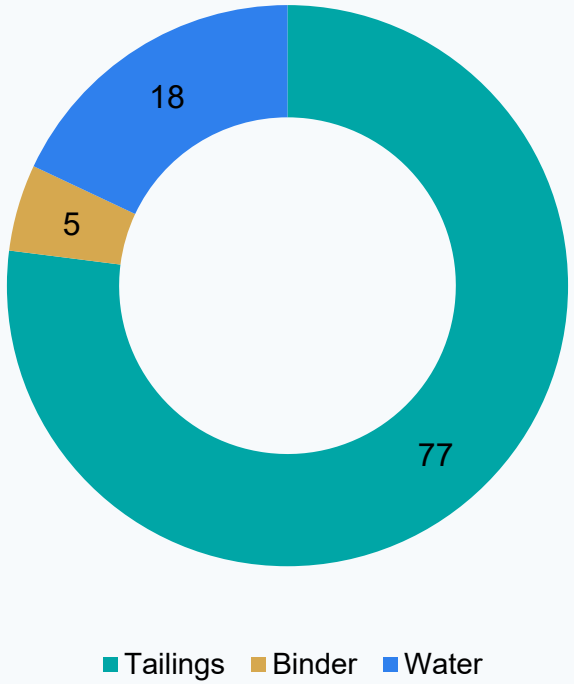
Highest direct CO_2 value; needs reactivity, durability and standards pathway.

Lane 4 — Alkali-activated / hybrid binders

High technical value; activator cost/carbon and market acceptance must be managed.

Lane 1: cemented paste backfill and mine infrastructure

The fastest high-volume route is often near the mine, not the concrete plant.



70–85 wt% tailings

2–10 wt% binder

15–30 wt% water

Practical applications

Underground void backfill, mine roads, berms, haul-road subbase, non-public mine infrastructure, stabilized tailings monoliths.

Why it scales

It is closest to the source, absorbs very high tonnage, reduces surface storage burden and can use mine process water under controlled conditions.

What to optimize

Binder demand, pumpability/rheology, early UCS, long-term durability, sulfate/acid attack, leaching and mine-specific exposure.

Studies on Saudi copper mine tailings show CPB can achieve sufficient backfill strength; recent work combines copper tailings with Saudi natural pozzolan or cement kiln dust as partial binder replacements.

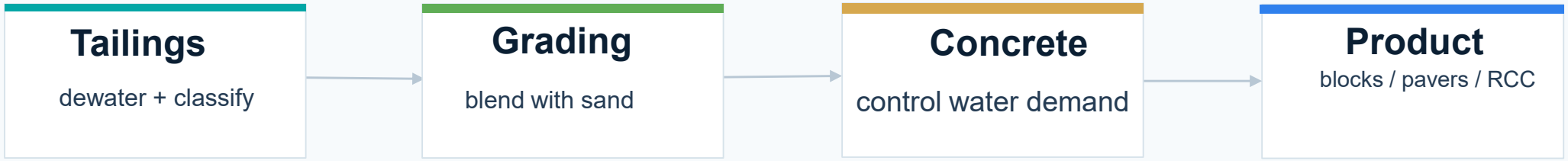
(Hefni et al. (2021) Saudi mine tailings backfill; Tanjung et al. (2025) copper tailings CPB with Saudi natural pozzolan)

Lane 2: fine aggregate, filler and packing modifier

A practical low-to-medium risk route for blocks, pavers, RCC and non-structural concrete.

How it works

Tailings can contribute as a graded fine fraction, micro-filler, nucleation surface or packing improver. Carbon reduction is indirect unless the filler enables lower binder content.



Best early products

Concrete blocks, interlocking pavers, precast curbs, pavement base, roller-compacted concrete, mine roads, low-exposure mass concrete.

Key controls

PSD, clay/fines content, water demand, organic/reagent residues, shrinkage, ASR risk, abrasion, density and surface texture.

Lane 3: supplementary cementitious material / cement replacement

This is the highest direct carbon-value lane, but it has the strictest performance gate.

A tailings-derived SCM must earn its place by reactivity, durability and consistency, not by availability alone.

Tier A — 5–10% cement replacement

Unactivated or lightly processed tailings; first structural screening window; focus on strength retention and leaching.

Tier B — 10–20% replacement

Requires better chemistry, finer particle size or blending with limestone/calcined clay/silica fume; monitor early strength.

Tier C — 20–35%+ replacement

Needs strong reactivity/activation or ternary design; target precast or controlled products before broad ready-mix.

What must be proven

Reactive potential

R3/calorimetry + strength activity

Durability

chloride, sulfate, ASR, shrinkage, carbonation

Stability

leaching and pH-dependent release

Consistency

lot-to-lot variability and plant QA

Carbon

LCA including processing and transport

Lane 4: alkali-activated and hybrid binders

AAMs can unlock tailings that are not ideal for conventional SCMs, but activator economics matter.

AAM/hybrid logic

Many tailings are crystalline and low-reactivity in Portland systems. Mechanical, th
dissolution of Si/Al/Ca/Fe phases and enable geopolymer or hybrid binders.

Tailings	Activation	Gel formation	Product
Si/Al/Ca/Fe phases	mechanical / thermal / alkali	N-A-S-H / C-A-S-H / hybrid	precast / blocks / mine structures

Potential

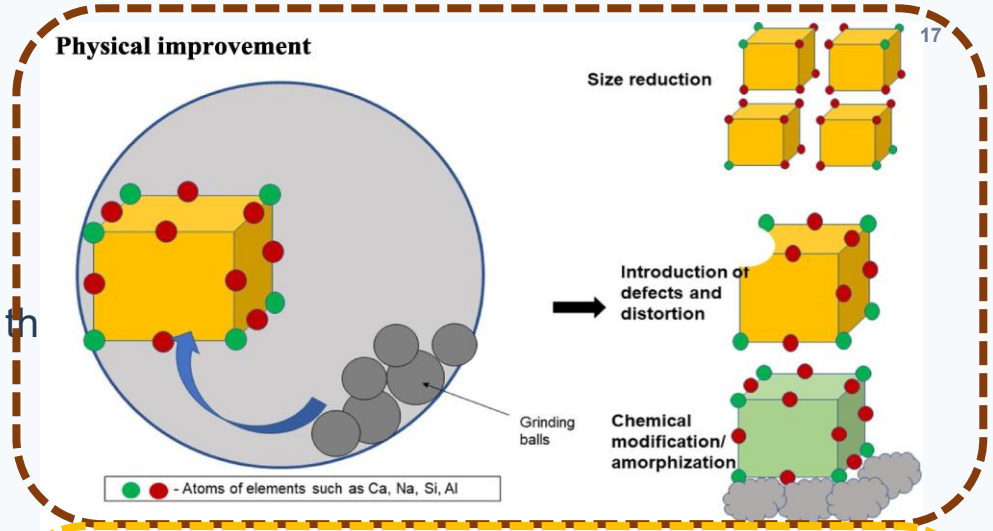
higher tailings loading, immobilization of selected contaminants, use in precast/geopolymer blocks, mine-site products and repair materials

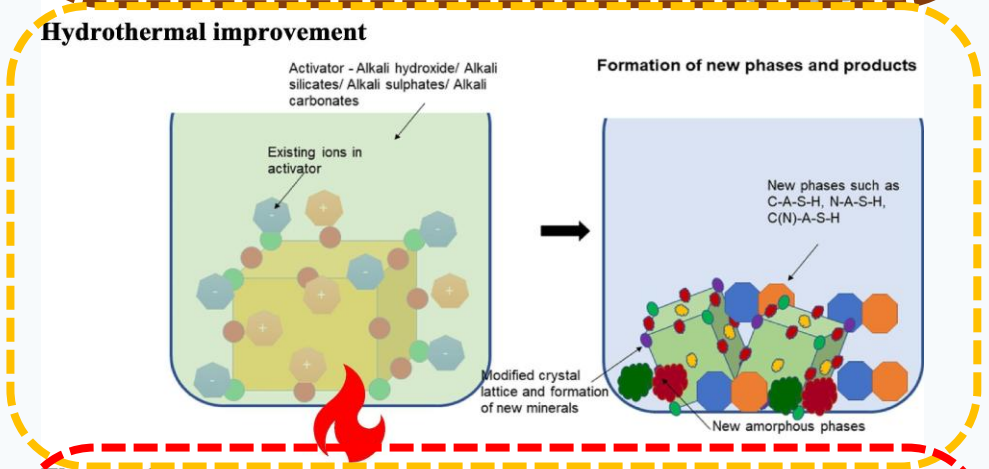
Risks

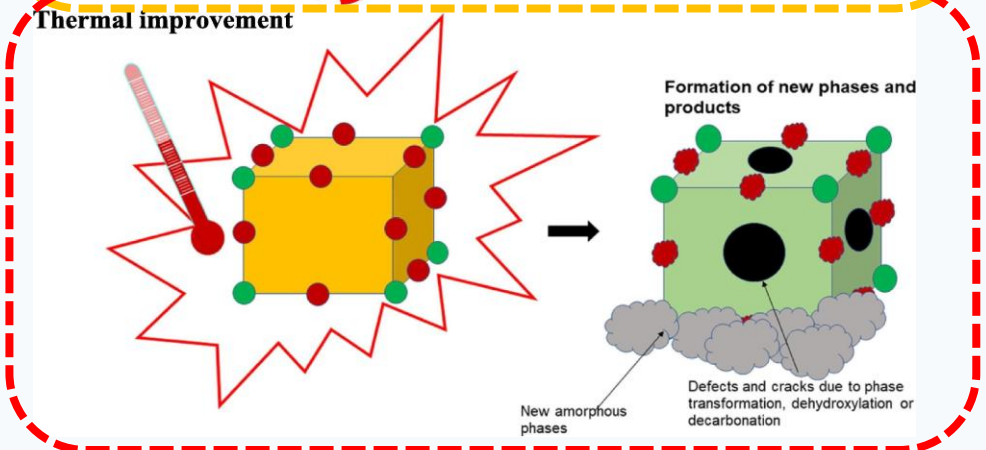
alkali activator cost/carbon, curing sensitivity, efflorescence, standardization, occupational handling and supply-chain acceptance

Best first markets

controlled precast, blocks, panels, mine infrastructure, non-reinforced products, backfill stabilization







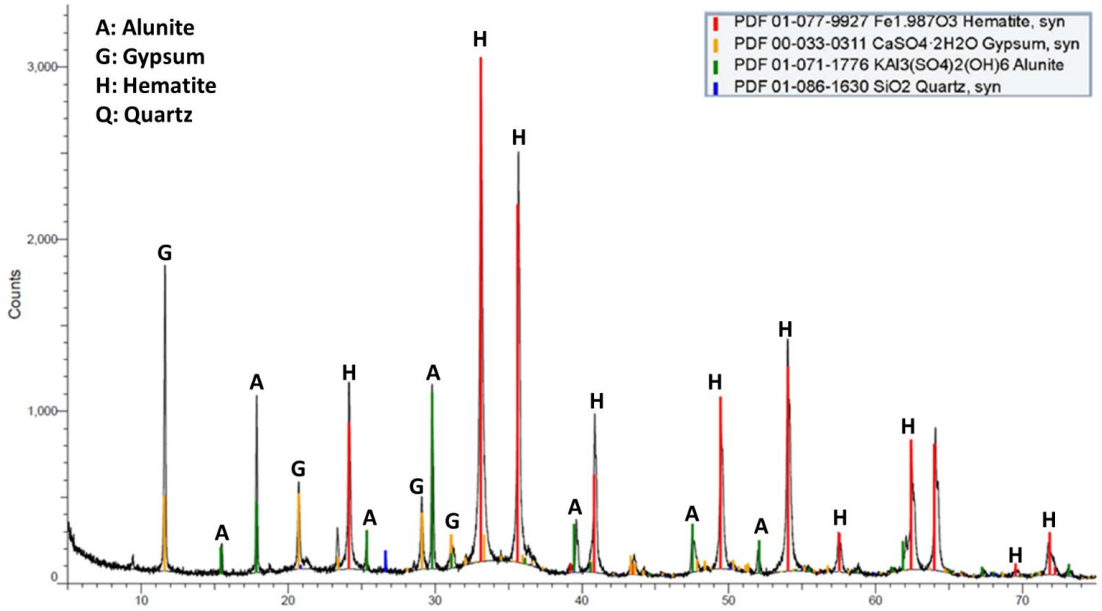


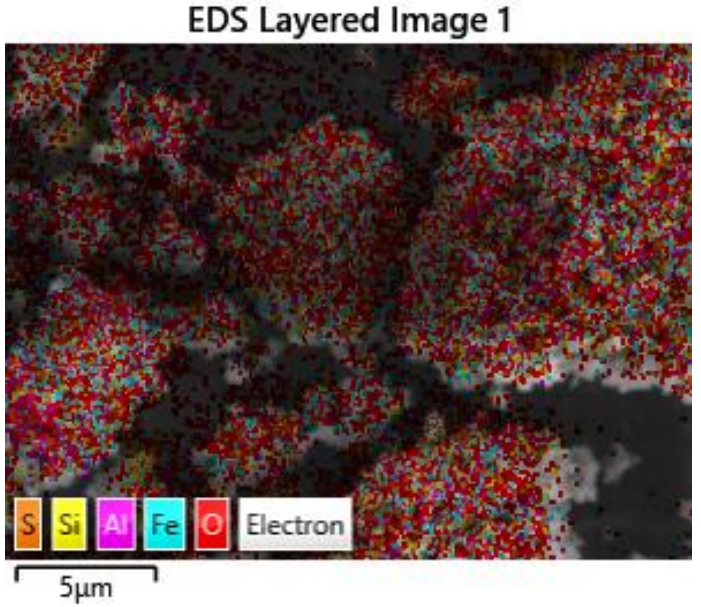
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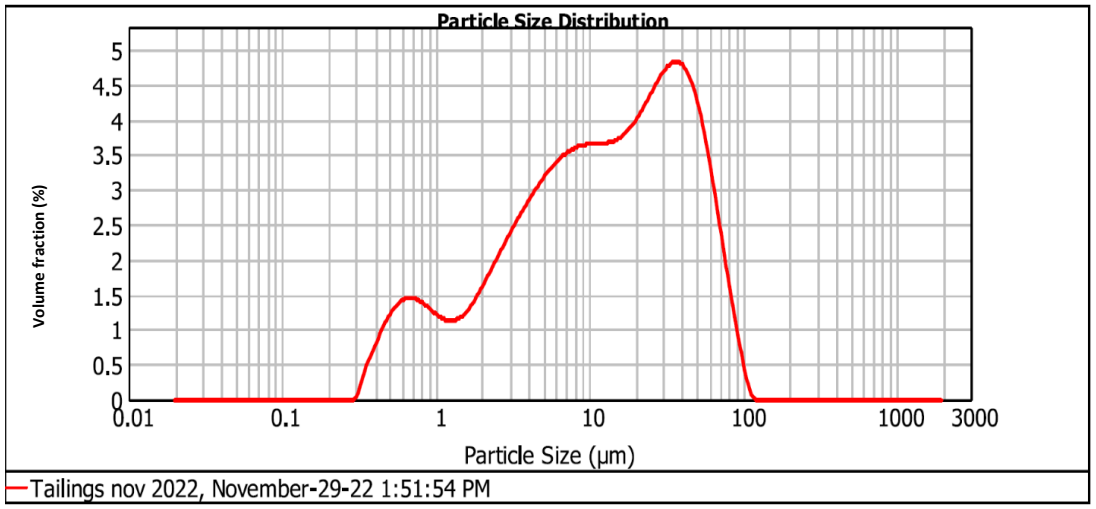


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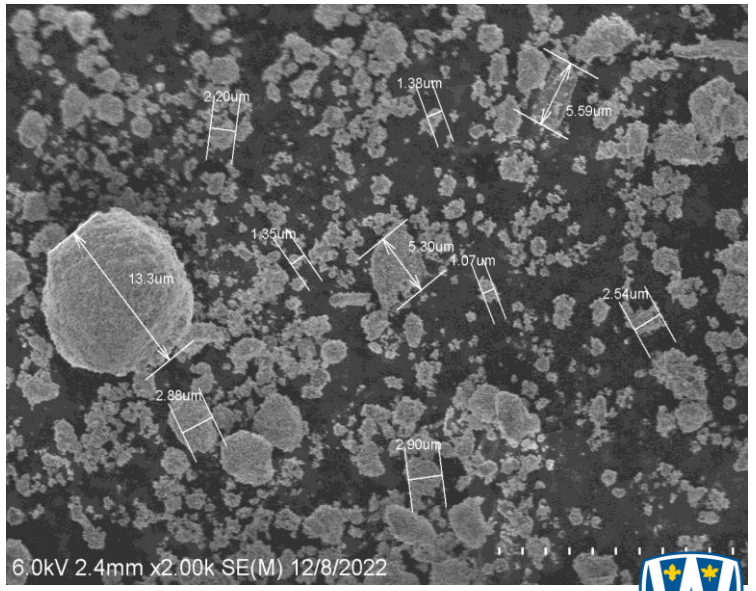
MT (a) as received (b) milled







Particle size distribution of MT



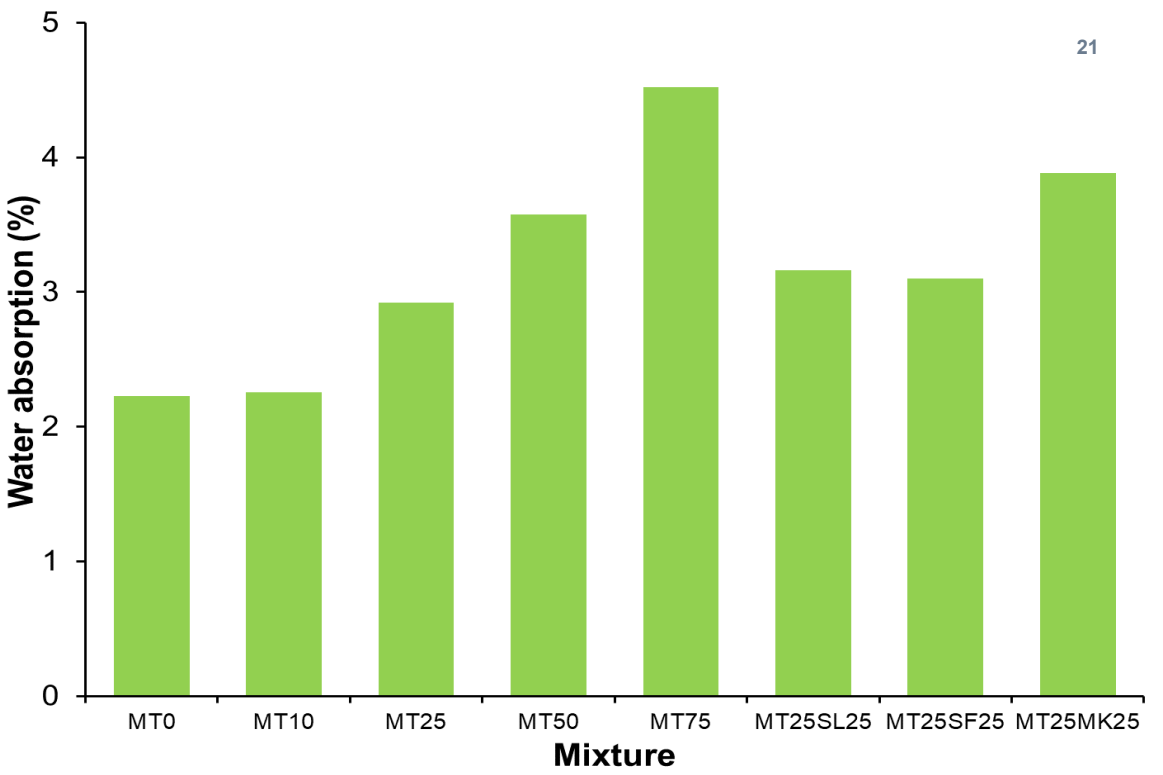
Replacement level of PC by weight (%)

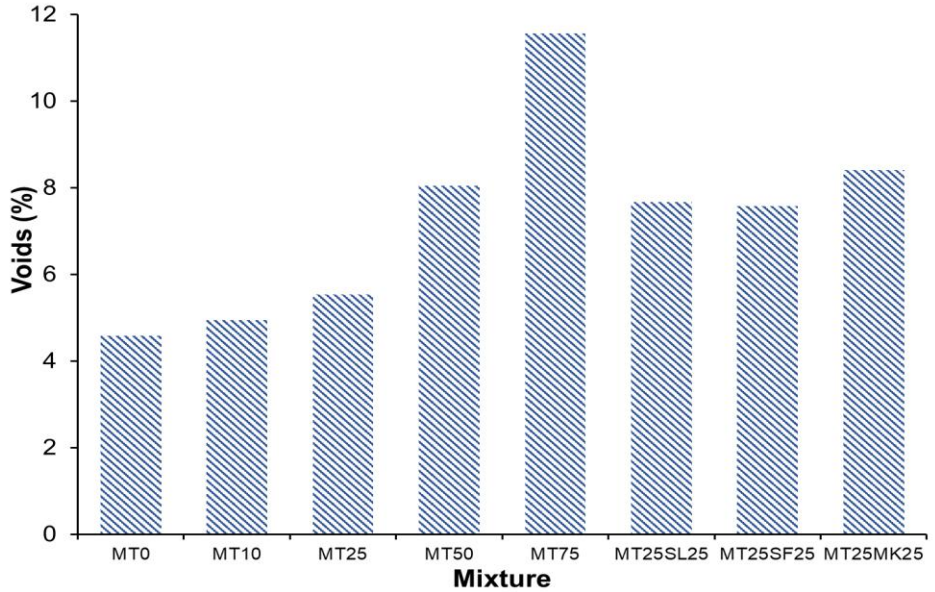
Mix. No.	Mixture ID	PC	MT	SL	SF	MK
1	PC	100	-	-	-	-
2	MT10	90	10	-	-	-
3	MT25	75	25	-	-	-
4	MT50	50	50	-	-	-
5	MT75	25	75	-	-	-
6	MT25SL25	50	25	25	-	-
7	MT25SF25	50	25	-	25	-
8	MT25MK25	50	25	-	-	25

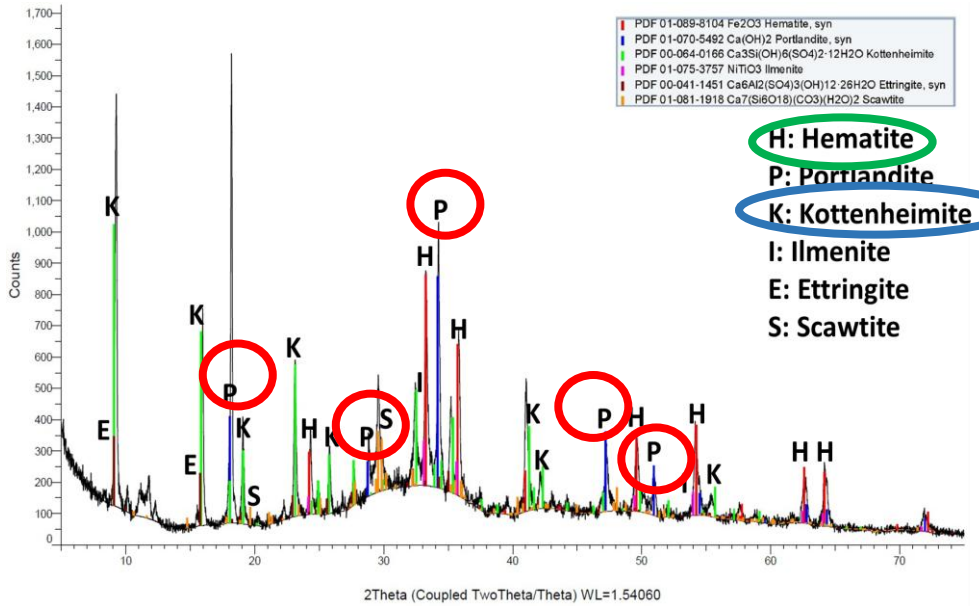
Base binder: Portland cement (PC)
Replacement levels: 0–75% MT by weight.
Additive combinations: MT25SL25, MT25SF25, MT25MK25.



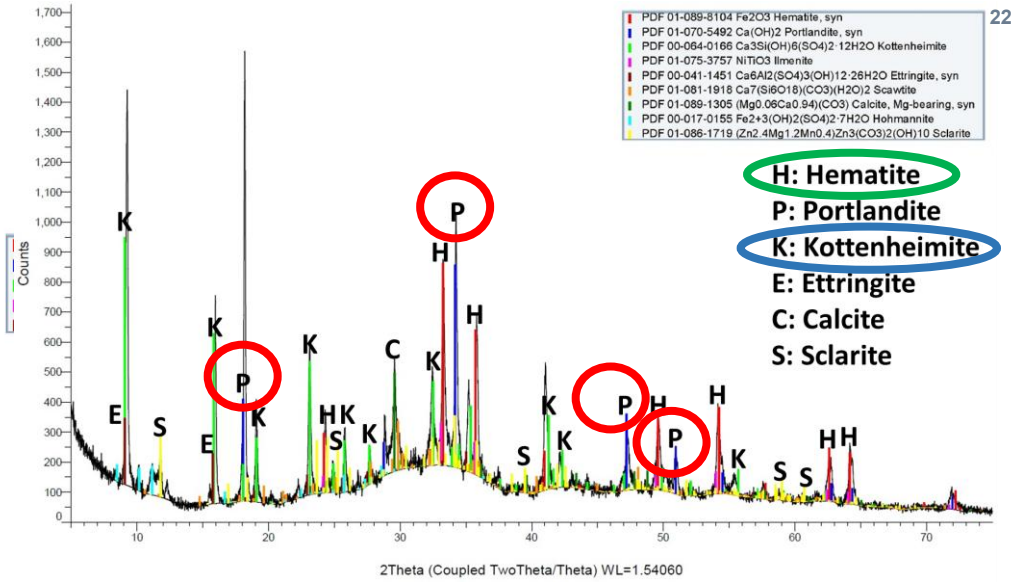
Compressive Strength (MPa
0
10
20
30
MT0
MT10
MT25
MT50
MT75
MT25SL25
MT25SF25
MT25MK25
Mixture
7 days
14 day
28 day


Water absorption (%)
0
1
2
3
4
5
MT0
MT10
MT25
MT50
MT75
MT25SL25
MT25SF25
MT25MK25
Mixture

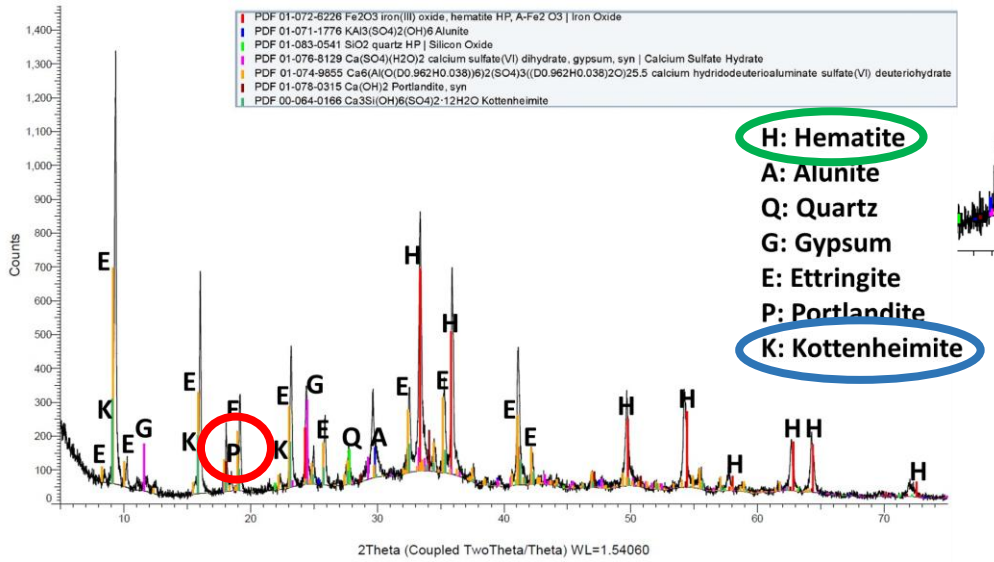

Voids (%)
0
2
4
6
8
10
12
MT0
MT10
MT25
MT50
MT75
MT25SL25
MT25SF25
MT25MK25
Mixture



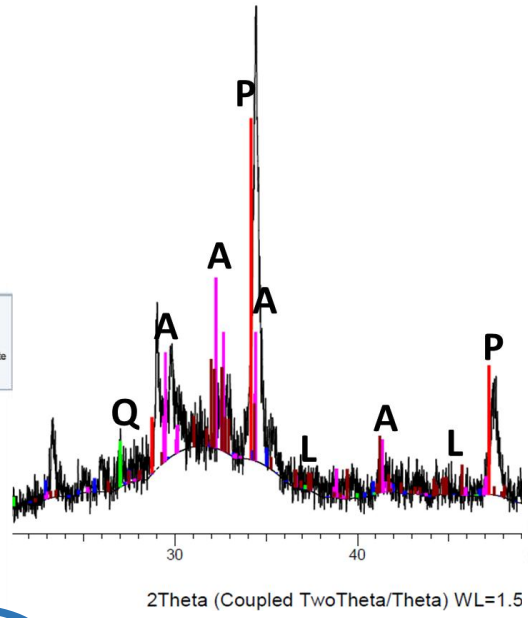
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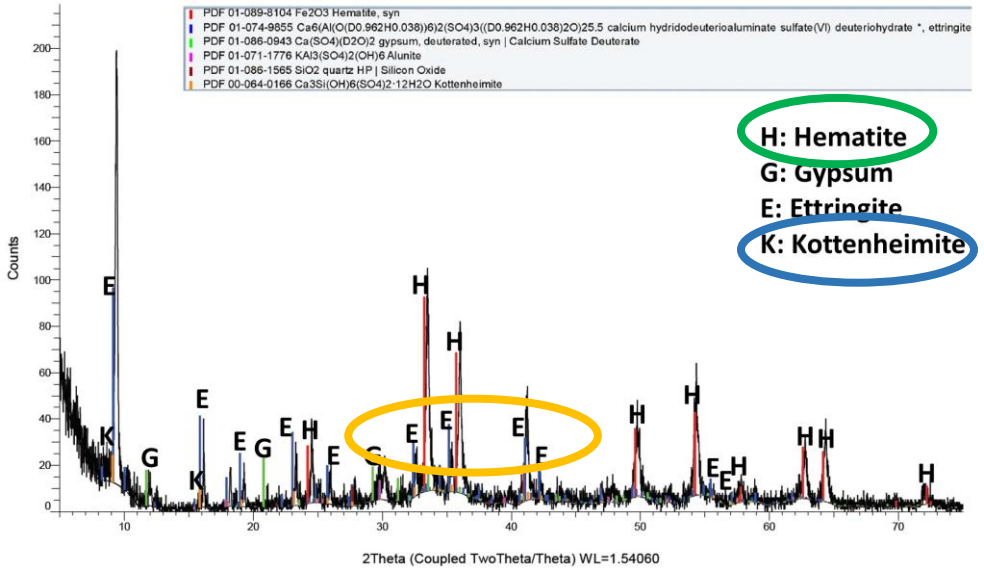


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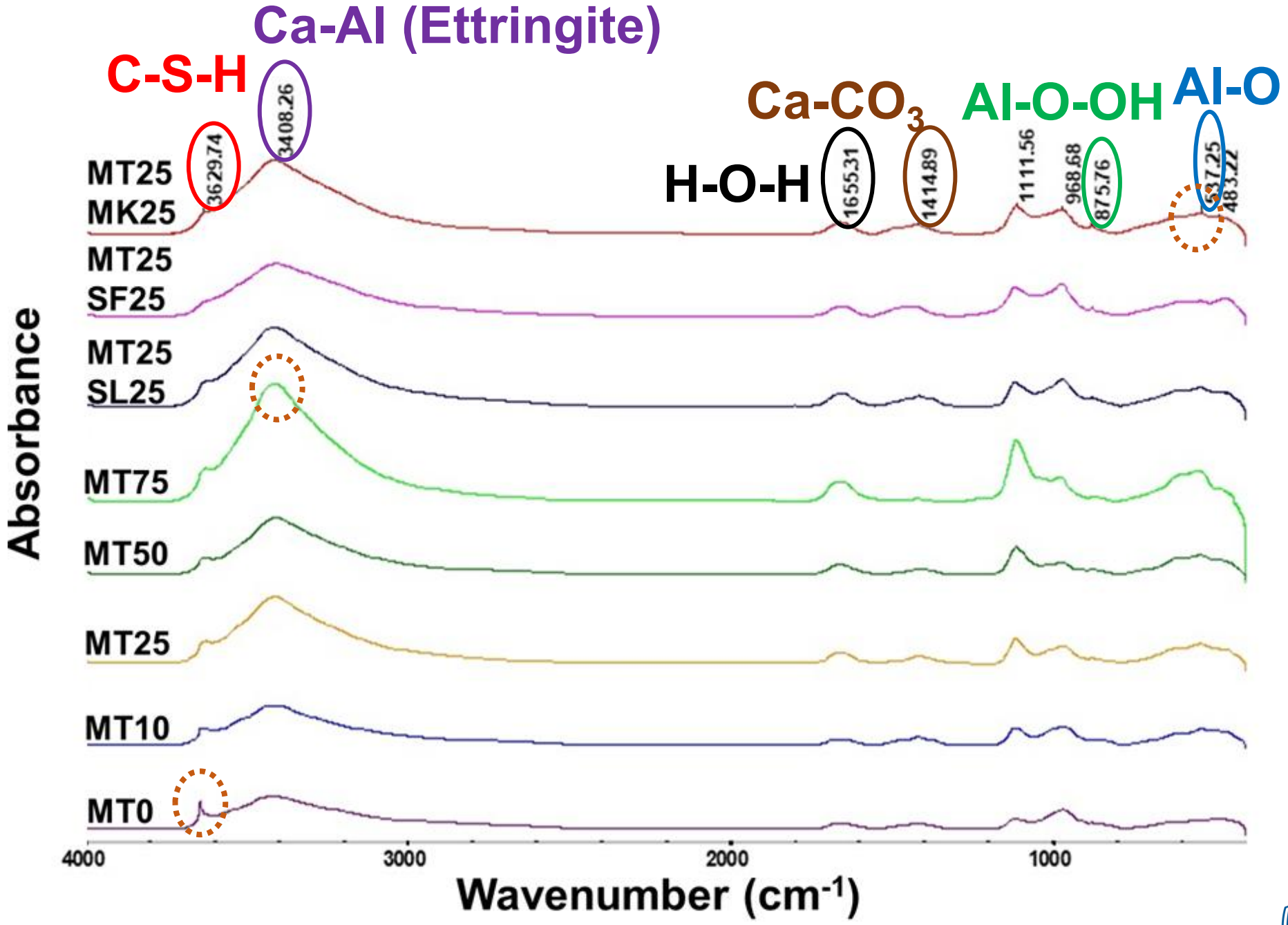
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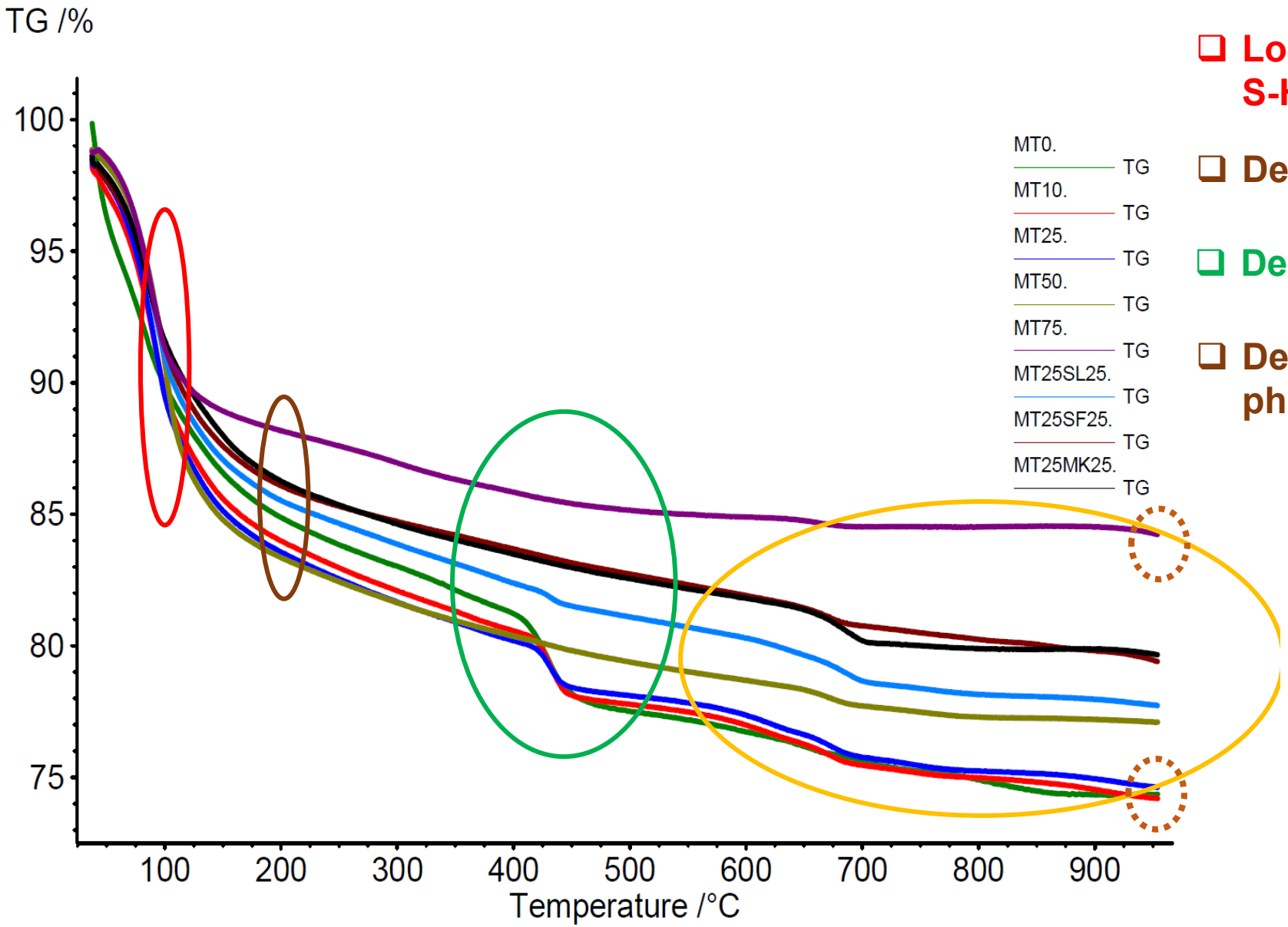


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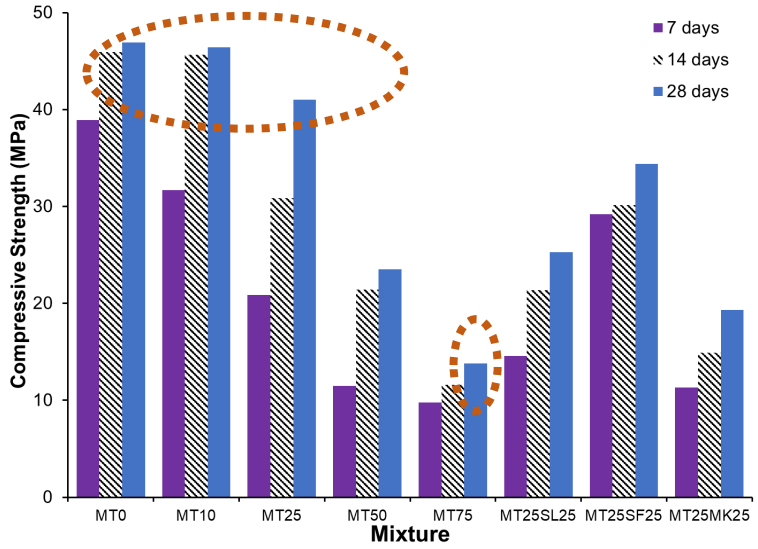
XRD diffractogram of (a) MT10 (b) MT25 (c) MT50 (d) MT75



FTIR of MT mixtures



- Loss of water & dehydration of C-S-H gel
- Dehydration of ettringite
- Decomposition of portlandite
- Decomposition of carbonate phases



TGA of MT mixtures

Standards and acceptance pathway

Tailings-derived materials will need performance-based routes, not only prescriptive oxide limits.

1 Classify as candidate material

material passport; legal waste/byproduct status; source traceability

2 Benchmark against known frameworks

ASTM C618 natural pozzolan / fly ash; ASTM C1897 R3 reactivity; EN 197-5 composite cement logic

3 Prove concrete performance

strength, workability, durability, leaching, shrinkage, permeability and field trials

4 Verify carbon and product claims

LCA, EPD, audited processing energy, transport distance and replacement factor

5 Codify acceptance

SASO/SBC/municipal specifications, procurement rules, producer QA and batch certification

For non-traditional SCMs, the commercial breakthrough is often not a new compressive-strength result; it is a trusted acceptance pathway.

Saudi deployment architecture

Mines
inventory, sampling, tailings handling

→

Processing hub
dewater, classify, grind/activate

→

Cement plant
blended cement / SCM stream

→

Concrete plant
mix design, QA, field trials

→

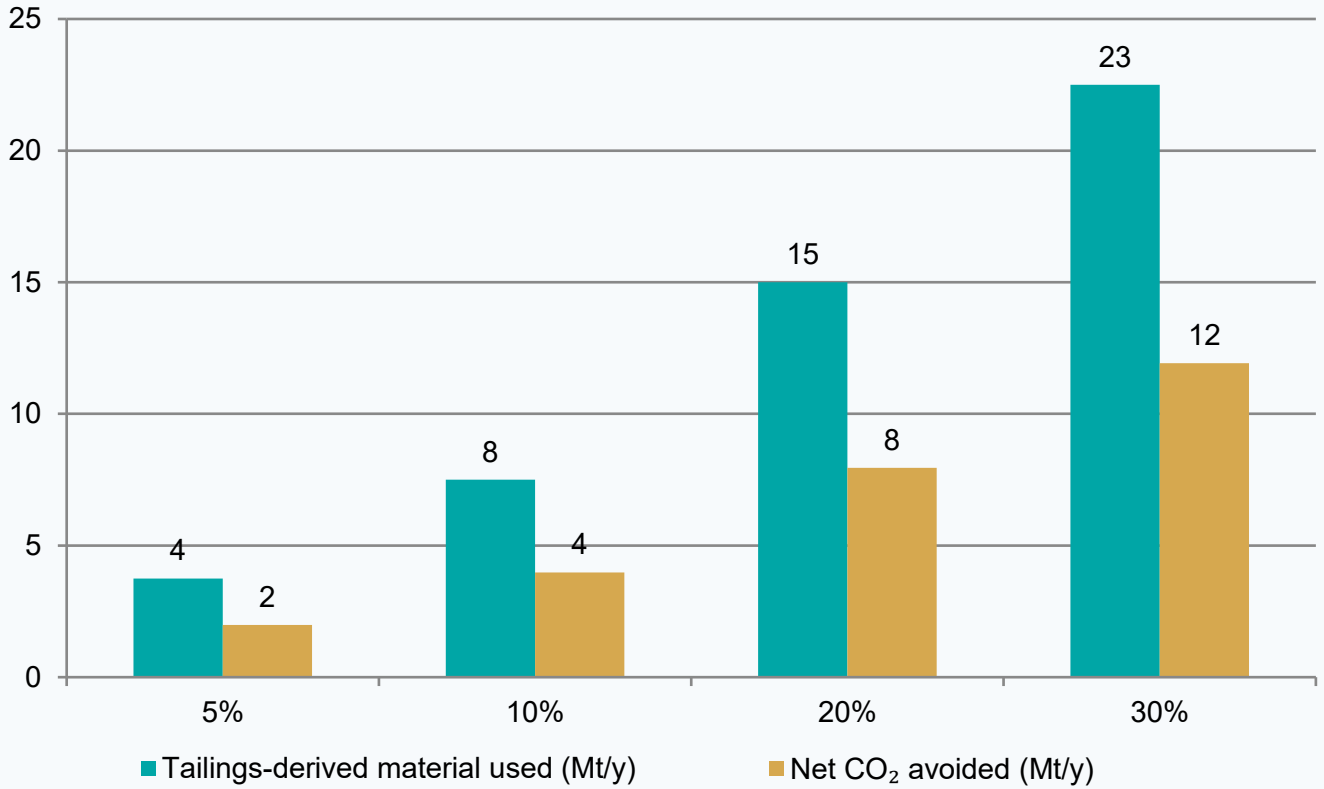
Project client
giga-projects, roads, housing

→

Data loop
EPDs, standards, procurement feedback

2030 adoption scenarios: quantitative potential

Illustrative base case: 75 Mt/y cement demand in 2030, 0.60 tCO_2/t cement baseline, 0.07 tCO_2/t processed tailings-derived binder.

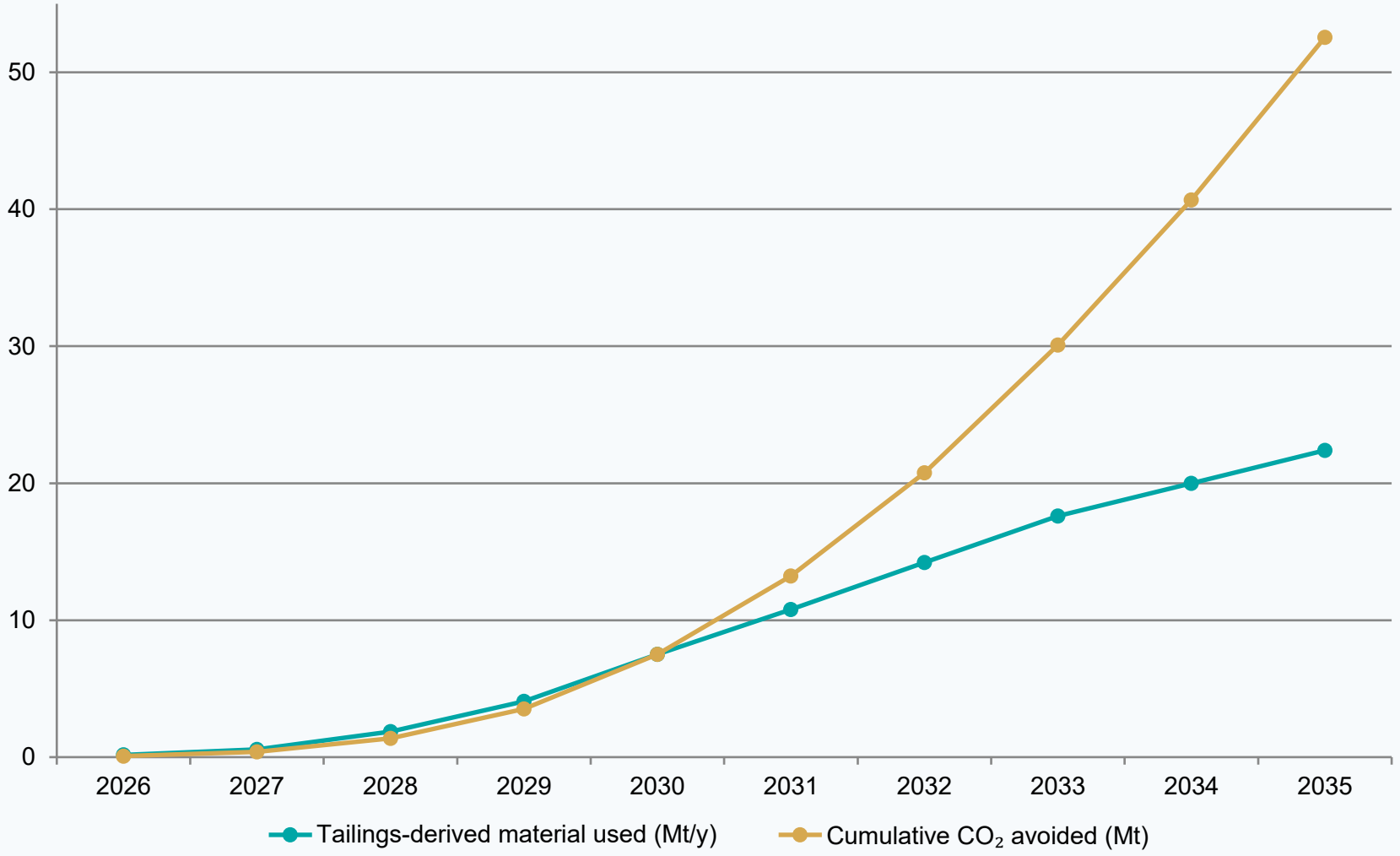


Adoption	Tailings use	CO_2 avoided	SGI 278 Mt/y share
5%	3.75 Mt/y	1.99 $MtCO_2/y$	0.7%
10%	7.50 Mt/y	3.98 $MtCO_2/y$	1.4%
20%	15.0 Mt/y	7.95 $MtCO_2/y$	2.9%
30%	22.5 Mt/y	11.93 $MtCO_2/y$	4.3%

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RESILIENT INFRASTRUCTURE AND SUSTAINABLE MATERIALS LAB

Engineering
University of Windsor

A plausible 2026–2035 ramp



~22 Mt/y

Tailings-derived material used by 2035 in a 28% adoption scenario.

~52.6 Mt

Cumulative net CO_2 avoided from 2026–2035 under the illustrative ramp.

3 phases

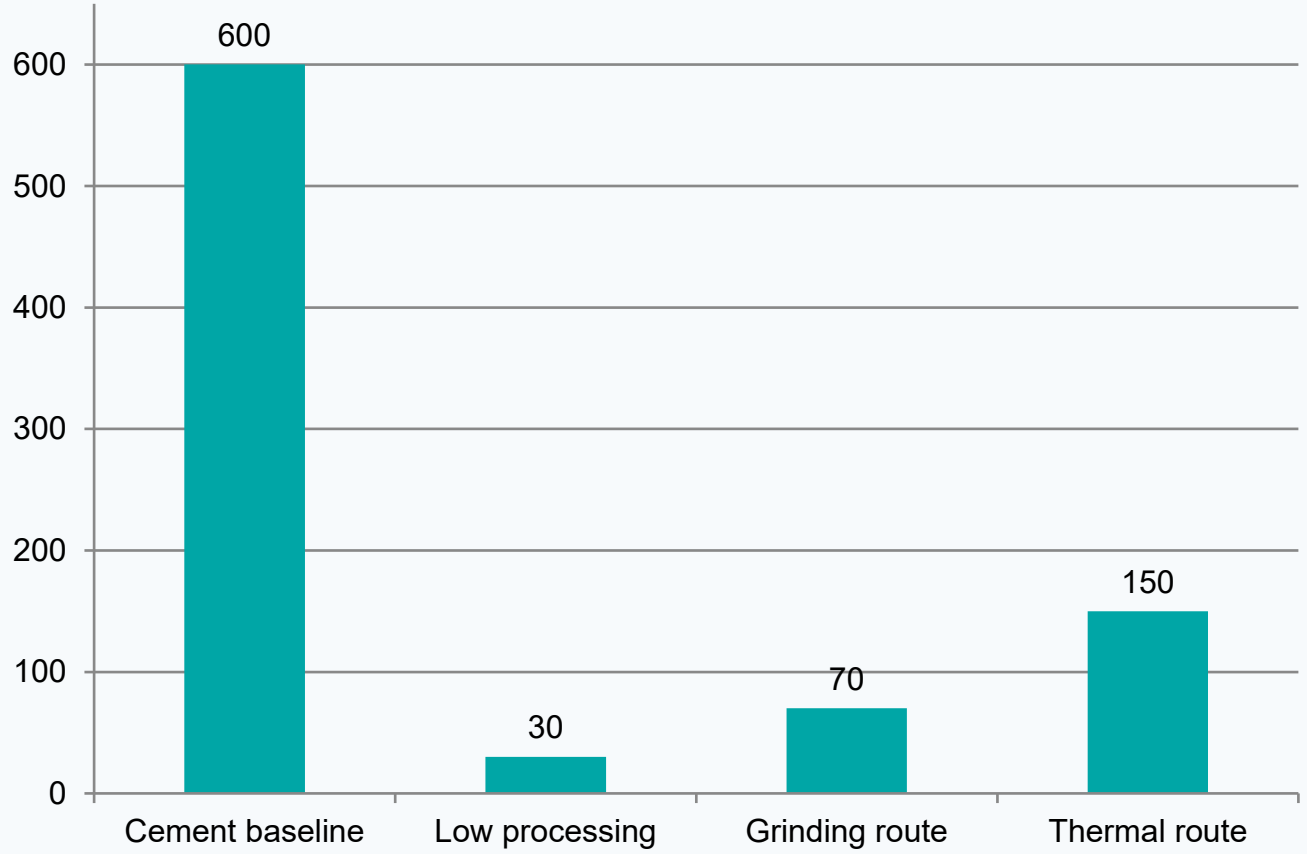
Pilots → regional hubs → procurement-backed scale.

Embodied carbon logic per tonne of cement displaced

The net value depends on processing intensity and transport, but the clinker displacement signal is large.

Base calculation

Cement baseline ≈ 0.60 tCO_2/t
Processed tailings binder ≈ 0.07 tCO_2/t
Net avoided ≈ 0.53 tCO_2/t displaced



What to count

Processing electricity/fuel, drying, grinding or calcination, activator production, transport, admixture change and replacement ratio.

What not to overcount

Avoid assigning zero impact by default; tailings still need handling, QA and sometimes energy-intensive treatment.

Why it still matters

Even with 70 $kgCO_2/t$ processing, each tonne replacing cement saves roughly 0.53 tCO_2 before any storage or aggregate benefits.

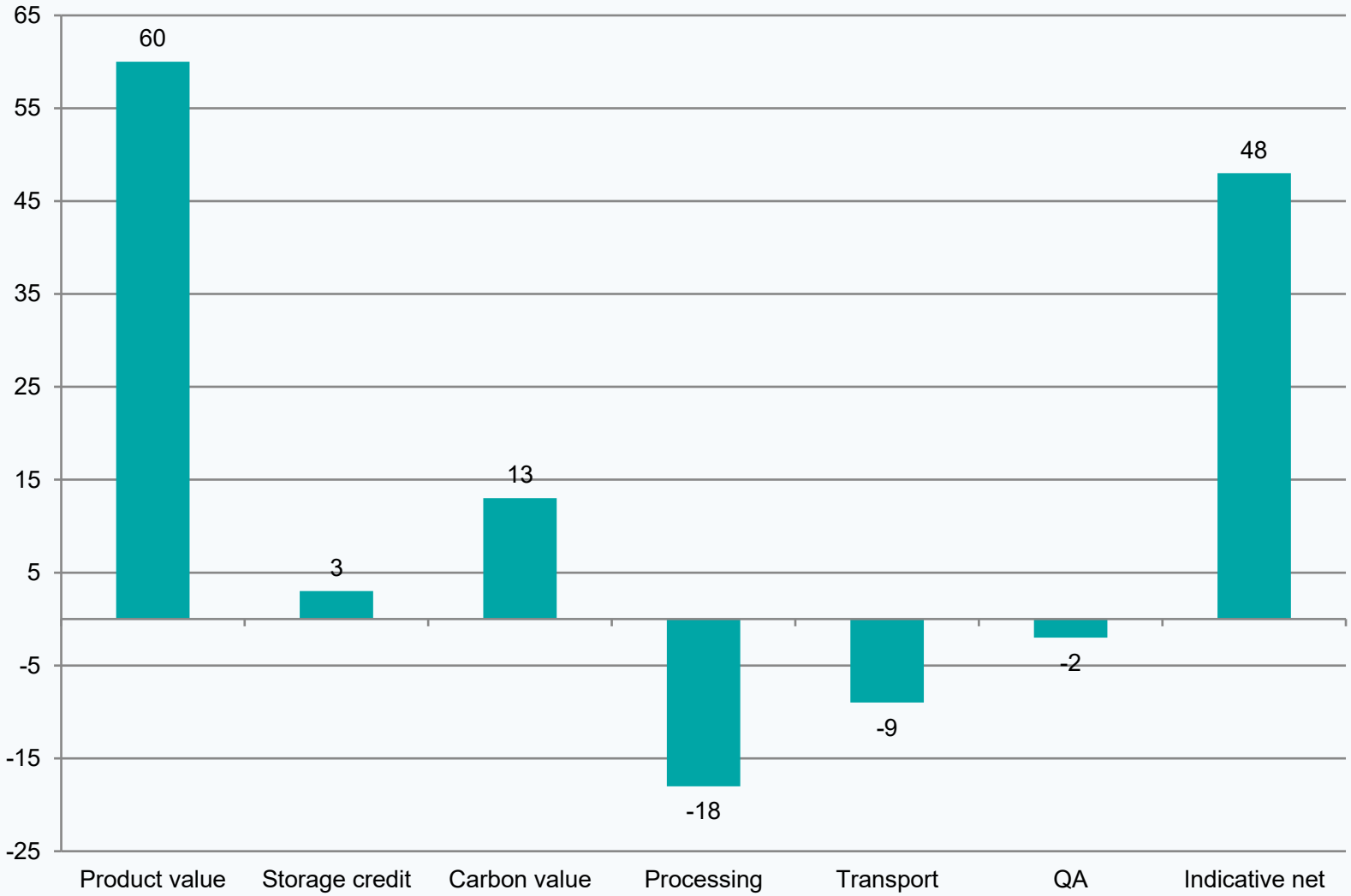
Unit economics

Illustrative gross value stack per tonne of processed tailings-derived SCM.

Base case assumptions

Product value $60/t
Storage/handling credit $3/t
Carbon value $25/t$CO_2$ × 0.53 = $13/t
Processing $18/t
Transport 100 km × $0.09/t-km = $9/t
QA/certification $2/t

Indicative gross margin ≈ $48/t before capex, overhead and contractual risk allocation



Cost sensitivity: processing tier × transport radius

Indicative gross value ($/t processed tailings-derived SCM) using the base assumptions.

Assumptions: product value $60/t, carbon value $25/t$CO_2$, storage credit $3/t, QA $2/t, transport $0.09/t-km, net CO_2 avoided 0.53 t/t.

Processing tier / distance	50 km	150 km	300 km
Low: classify/dry ($10/t)	$60/t	$51/t	$37/t
Medium: grind ($20/t)	$50/t	$41/t	$27/t
High: thermal/advanced ($45/t)	$25/t	$16/t	$2/t

Near-source processing wins

Drying, classification and grinding should be located where moisture and bulk transport are minimized.

Thermal routes need premium value

Calcination or chemical activation must be justified by higher replacement ratios, premium products or low-carbon heat.

Transport can dominate

A low-reactivity tailings stream hauled long distances may lose its economic and carbon advantage.

Business model: who owns the risk and value?

Mine operator

source control, sampling access, tailings handling, environmental data and long-term liability management

Processor / hub operator

dewatering, classification, grinding/activation, batch QA, logistics and product documentation

Cement / concrete producer

product formulation, performance validation, plant QA and market-facing claims

Regulator / standards body

acceptance criteria, leaching/durability protocols, construction code alignment

Project client

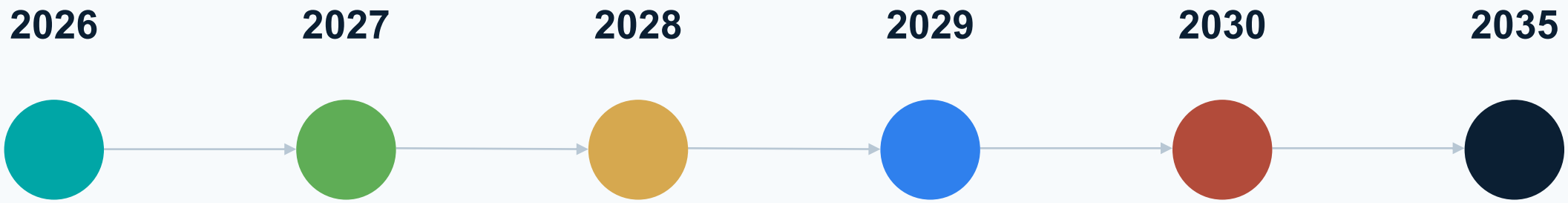
demand signal, EPD requirements, low-carbon procurement and field trial sites

Commercial success comes when tailings are no longer treated as a waste exception, but as a qualified raw material with contracts, QA, warranties and EPDs.

Pilot KPI scorecard

KPI family	Minimum metric	Pass signal for scale-up
Material consistency	XRF/XRD/PSD variability across lots	defined control limits and batch certification
Performance	compressive strength, set, workability, shrinkage	meets product-specific target with margin
Durability	chloride, sulfate, permeability, ASR, carbonation	equal or better than reference for intended exposure
Environmental	powder and monolithic leaching, acid generation, dust	below regulatory thresholds with safety controls
Carbon	$kgCO_2/t$ product and $kgCO_2/m^3$ concrete	verified reduction vs reference; EPD-ready data
Economics	\$/t processed, $\$/tCO_2$ avoided, capex and logistics	positive net value or acceptable abatement cost
Scalability	available tonnes, logistics radius, QA frequency	multi-year supply and offtake contract pathway

Roadmap to 2030 and 2035



Inventory + screening
national tailings database, common sampling/testing protocol, first material passports

Pilot products
CPB, blocks/pavers, SCM blends and AAM prototypes with LCA and leaching data

Regional hubs
processing/logistics hubs near priority mining-cement corridors

Standards + EPDs
performance specifications, product category rules and verified EPD templates

Procurement scale
giga-project and public works demand for verified low-carbon materials

Circular system
multi-hub national supply chain and exported know-how for arid mining regions



Closing messages for Saudi and global stakeholders

1. **Qualify first** — Source characterization, reactivity, leaching and durability gates are non-negotiable.
2. **Use a portfolio** — Backfill, filler, SCM and AAM routes solve different parts of the volume–value problem.
3. **Scale where logistics work** — Co-location, hubs and transport radius determine both cost and carbon.
4. **Make claims verifiable** — EPDs, material passports and standards alignment turn innovation into procurement-ready products.
5. **Build the system** — FCI can align mines, cement producers, regulators and giga-project clients into a national circular-material platform.

Mine tailings in cementitious materials should be treated as a strategic supply-chain opportunity. technically rigorous, commercially disciplined and verified by performance.

Selected sources

1. Adesina, A. (2020). Recent advances in the concrete industry to reduce its carbon dioxide emissions. Environmental Challenges, 1, 100004.

2. Adesina, A. & Kavgic, M. (2023/2024). Advancements in the synthesis and processing of alkali-activated materials: activators and precursors.

3. Adesina, A. (2025). Synthesis, characterization, and efficacy of alkali-activated materials from mine tailings: A review. Waste Management, 191, 23–46.

4. Adesina, A. (2025). Recent Trends in the Sustainability Improvement and Use of Wastes in Cementitious Materials. Elsevier.

5. Adesina, A. (2026). Characterization of mine tailings and utilization as partial replacement of cement. Physics and Chemistry of the Earth, 143, 104344.

6. IEA. Cement sector tracking: direct emissions intensity, clinker substitution, energy efficiency, low-carbon fuels and CCS pathways.

7. KAUST Future Cement Initiative (2025). Sustainable cement transformation and Saudi cement demand context.

8. Saudi Green Initiative. 2030 emissions reduction target and net-zero 2060 through circular carbon economy approach.

9. UNDRR / Global Tailings Review / UNEP. Tailings scale, tailings risk, and Global Industry Standard on Tailings Management.

10. ASTM C618 and ASTM C1897/R3; EN 197-5 composite cement; performance-based acceptance literature.

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Thank you!

Do you have any questions?

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